

An aerial view of a synthetic landscape. A blue river flows from the top center towards the bottom left. The surrounding terrain is a mix of green and brown, representing fields and vegetation. There are several small, dark, irregular shapes scattered across the landscape, which could be trees or small structures. In the lower right, there is a cluster of brown, rectangular shapes that look like buildings or a small town. The overall scene is a computer-generated environment used for synthetic vision systems.

Database Integrity for Synthetic Vision Systems

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2002 Workshop Review

Database Integrity for Synthetic Vision Systems

Prioritized list of certification issues and future research needs

1. Terrain database accuracies (evaluations, integrity monitors)
2. HMI is a major concern
3. Training
4. Failure modes

Selected comments taken from minutes...

"Can be hazardous misleading"

"SVS SA and terrain awareness is not a warning system"

"If its good enough for TAWS, should be OK for SVS"

"Navigation using TAWS is not permitted"

"Don't stop certification of equipment due to mis-use, since a lot of certified systems can be mis-used."

"Mountainous night VFR flight may be a challenging situation. Pilots could use lower altitudes since they can 'see' the terrain on the SVS display."

"Fear of HMI on PFD is stifling progress."

"NAV database process is uncertified."

"Hard to separate SA and navigation roles of SVS."



Overview

Database Integrity for Synthetic Vision Systems

Database integrity

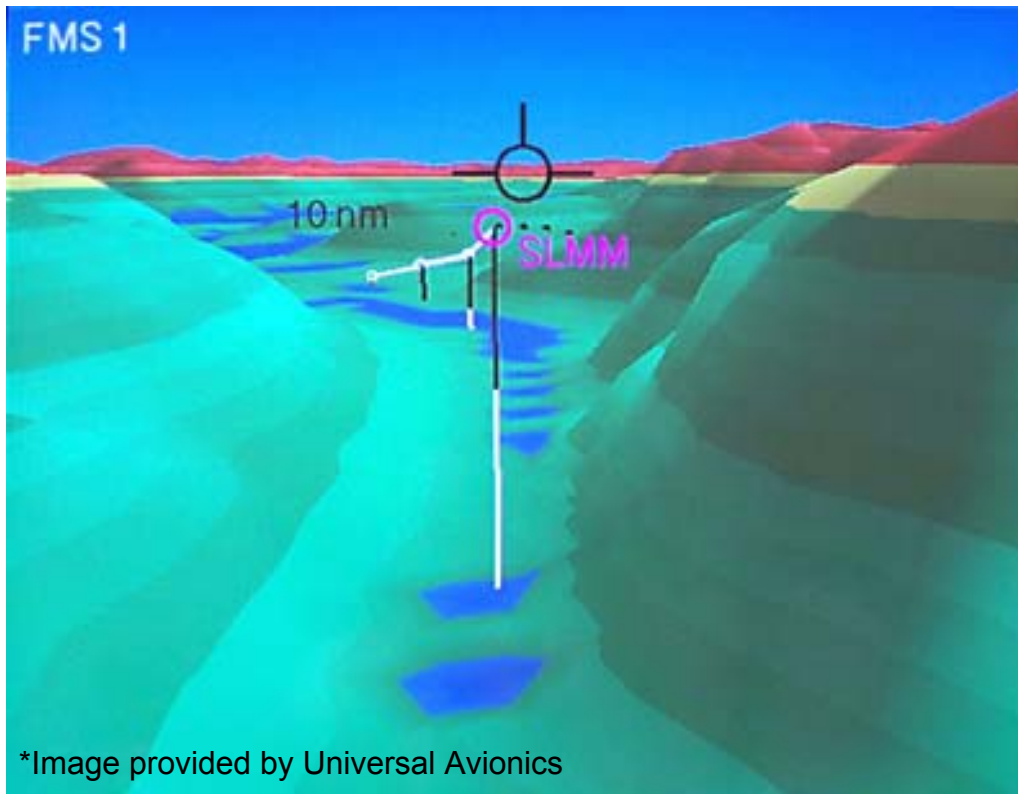
- What is it... **“Trust”**
- Why is it important... **“Flexibility”**
“Safety margin”
- How can we get it...
 - “Quality source data”**
 - “Certified life-cycle process”**
 - “Real-time monitoring”**



Definition of Terms (1/3)

Database Integrity for Synthetic Vision Systems

Synthetic Vision System (SVS): a real-time system that utilizes a precise positioning sensor, stored geo-spatial data, and sensed surveillance data to provide a view of the aircraft's external environment



Geo-spatial Data: data that represents a spatial location that is referenced to the earth (geo-referenced) or a model of the earth (WGS-84 ellipsoid)

Examples:

- Terrain models (DEMs)
- Obstacle data
- Nav data (path/tunnel)
- ADS-B traffic data
- GPS positioning data
- Feature data (water bodies, airport features, etc.)



Definition of Terms (2/3)

Database Integrity for Synthetic Vision Systems

‘INTEGRITY’

Data integrity: data errors could cause, or contribute to, the failure of a system function resulting in a *catastrophic, severe, major, minor, or no effect* failure condition

[ICAO Annex 15], [RTCA DO-178B], [FAA AC 23.1709]

Data processing integrity: degree of assurance that aeronautical data and its value have not been lost or altered since the data origination or an authorized amendment

[ICAO Annex 14], [ICAO Doc 9674-AN/946], [RTCA DO-200A], [RTCA DO-201A], [RTCA DO-272], [RTCA DO-276]

System integrity: probability that the system does not provide Hazardous Misleading Information (HMI) to the pilot

For GPS: "...the ability of the system to provide timely warnings to users when the system should not be used for navigation"

[Brown, Global Positioning System: Theory and Applications], [RTCA DO-245]



Definition of Terms (3/3)

Database Integrity for Synthetic Vision Systems

Spatial data integrity (*SDI*): integrity at time t_u

Temporal data integrity (*TDI*): integrity at time t_x ($t_u < t_x < t_{u+1}$)

$$TDI = f(SDI, t)$$

For terrain databases, usual assumption is: $TDI = SDI$

For obstacle databases and ADS-B traffic data: $TDI \neq SDI$



Integrity vs. other data attributes

Database Integrity for Synthetic Vision Systems

Example: terrain databases

(RTCA DO-276 attributes)

- Horiz. accuracy
- Vert. accuracy
- Post-spacing
- Down-sampling rule
- Penetration level
- Reference system
- Coverage
- Surface type
- Timestamp
- Data processing integrity

System
context



(Data integrity)

Catastrophic system failure

(System integrity)

Hazardous Misleading Info (HMI)

Misleading Terrain Info (MTI)

“Timely warnings when the system should not be used for its intended function”

Operational
context



If you don't leave the ramp, $\text{Pr}[\text{MTI}] = 0$!!



Conundrum*

Database Integrity for Synthetic Vision Systems

**Operational requirements determine
integrity requirements**

**Integrity performance determines
operational constraints**

*A paradoxical, insoluble, or difficult problem; a dilemma. –American Heritage Dictionary



SVS Operations (Hypothetical)

Database Integrity for Synthetic Vision Systems

Context



- SVS as PFD in IMC
- Areas of significant terrain
- Low altitude operations

It is assumed that $\Pr[\text{MTI}] = 0$
when operating

- in VMC
- at high altitude

Categories

Nominal Ops

- Following standard procedures
- In the tunnel and/or tracking the FD

Off-nominal Ops

- Cannot stick to standard procedures
- Tunnel/FD unavailable or 'out of sight'

Extended Ops

- Ill-equipped runway
- Dynamic paths
- Emergency descents
- Unknown/unfamiliar territory

Need for Integrity

Nominal Ops – compelling? conflicting info?

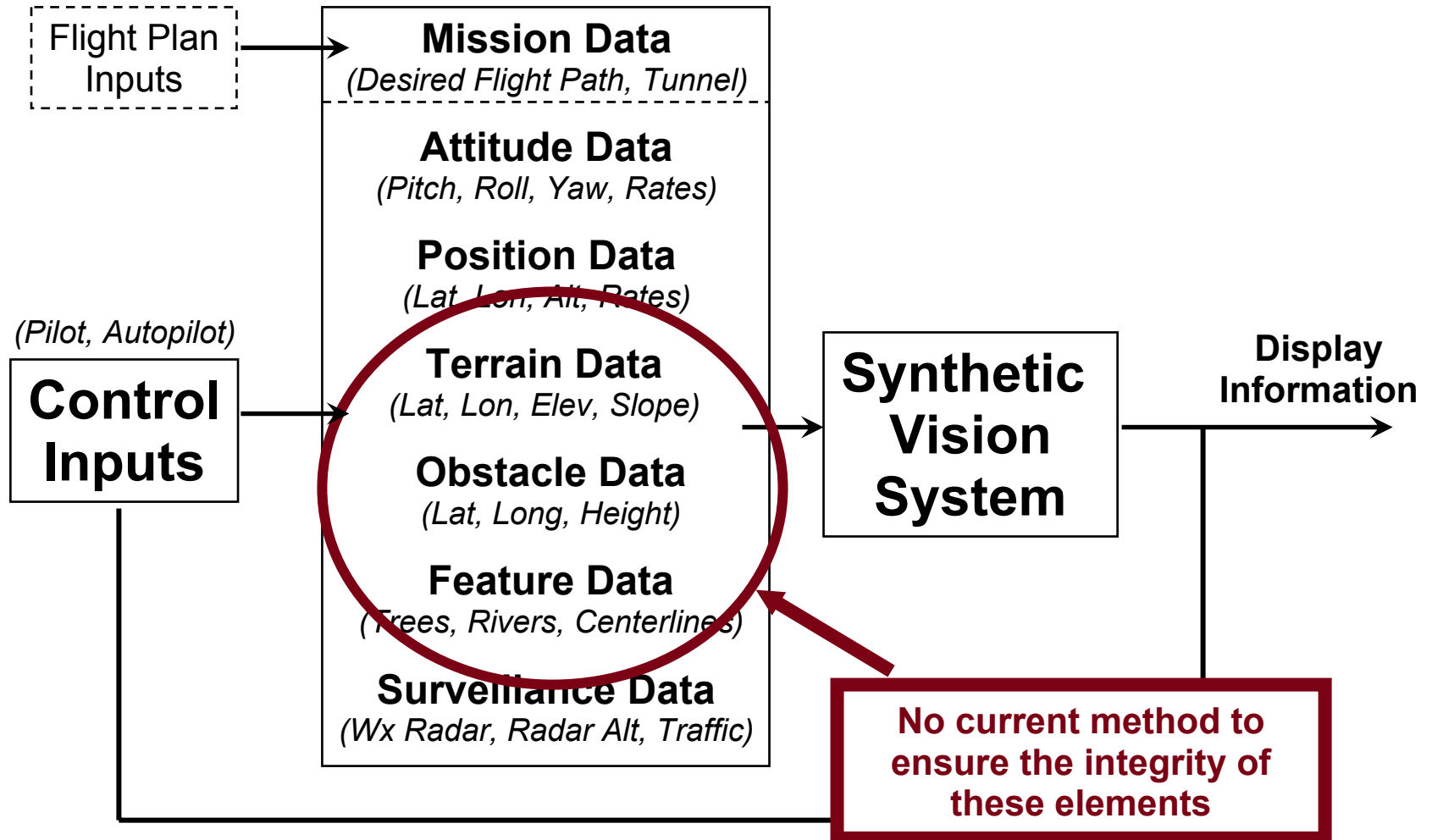
Off-Nominal Ops – terrain-referenced nav?

Extended Ops – terrain as primary nav input?



Another perspective...

Database Integrity for Synthetic Vision Systems





Review

Database Integrity for Synthetic Vision Systems

Database integrity – what is it...

- The extent to which a pilot can **trust** that the “picture” is not lying to him
- Ties data quality to “how the data is to be used”

Database integrity – why is it important...

- Without integrity, operational constraints may curtail benefits
- With integrity, SVS can achieve fullest potential
 - increased **safety margins**
 - operational **flexibility**
 - new procedures



Database integrity

Database Integrity for Synthetic Vision Systems

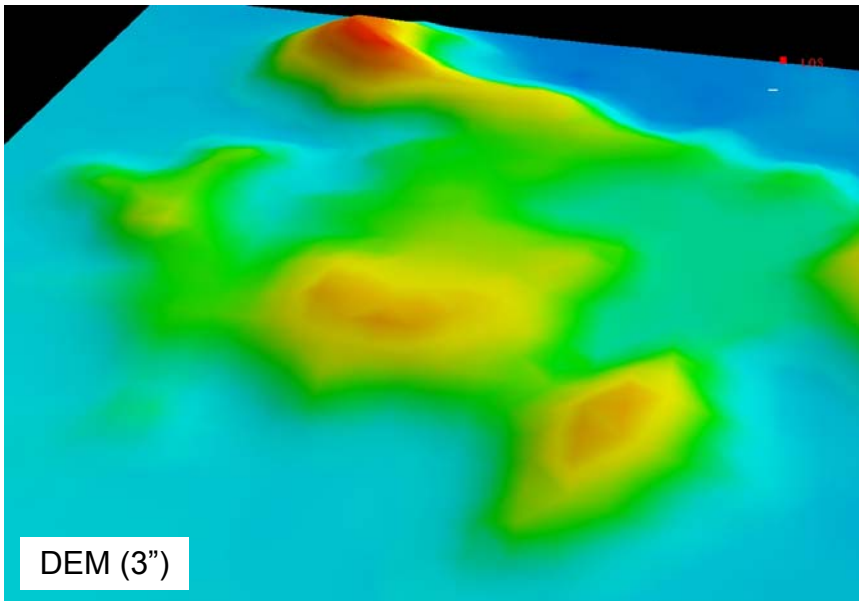
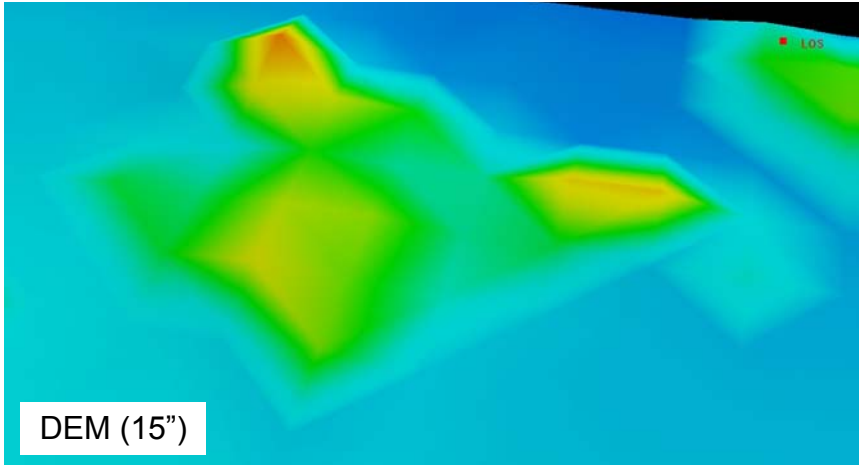
How can we get it...

- Quality source data
- Certified life-cycle process
- Real-time monitoring
 - Approach
 - Solutions
 - Challenges

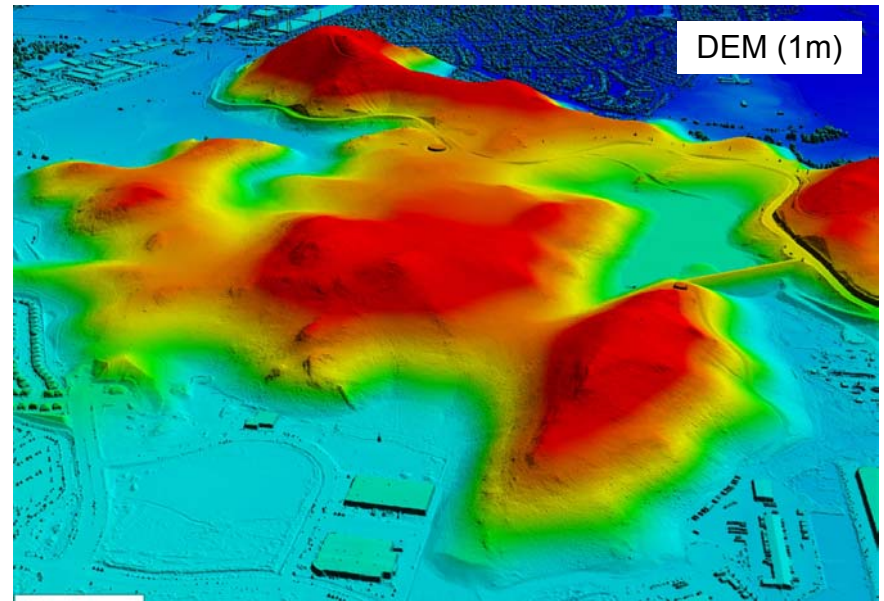


Quality source data (1/2)

Database Integrity for Synthetic Vision Systems



- Integrity begins at acquisition and degrades from there
- Metadata is critical to subsequent operational use
(e.g. who is the source, how was it obtained, sensor characteristics, validation method, reference system, quality attributes, timestamp, etc.)





Quality source data (2/2)

Database Integrity for Synthetic Vision Systems

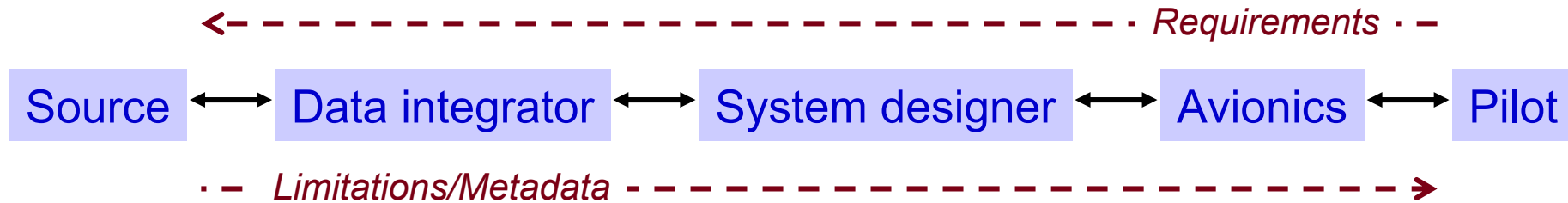
Recent accomplishments

- DO-272/ED-99, “User Requirements for Aerodrome Mapping Data”
- DO-276/ED-98, “User Requirements for Terrain and Obstacle Data”
- ICAO SARPS update in progress
- NASA/NIMA shuttle mission products (SRTM)
- NASA/SVS mapping investments
- SF-21 airport database initiative
- COTS developments
 - LiDAR mapping (e.g. OpTech)
 - Satellite-based mapping (e.g. Space Imaging)
 - Airborne SAR mapping (e.g. InterMap)



Life-cycle process

Database Integrity for Synthetic Vision Systems



Comprehensive process developed under NASA/Jeppesen CRA

Need for civil authorities to “certify” a process and encourage its use

Still may not be sufficient...

“One major concern with navigation data integrity is the control of the AIP source data. The problem occurs where erroneous data is put into a high integrity data chain. The result to the end user is high integrity erroneous data. States with the assistance of ICAO and organisations such as EUROCONTROL need to urgently address this issue.”
--Navigation Strategy for ECAC, JAA All Weather Operations Steering Group, Joint Aviation Authorities, Feb. 2003.

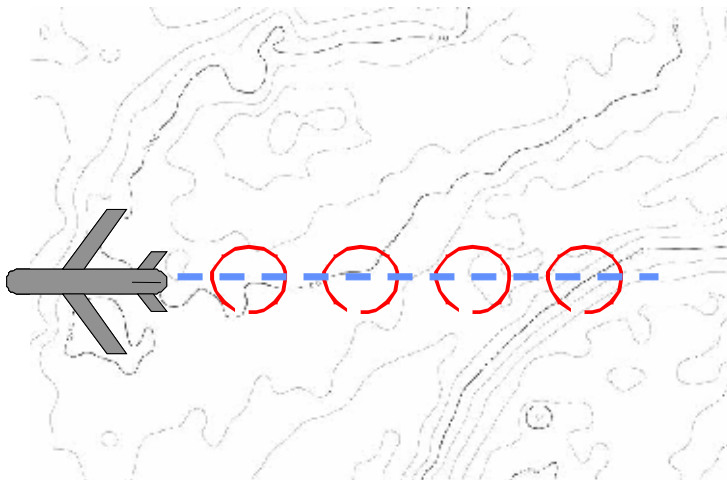


Real-time monitoring (1/2)

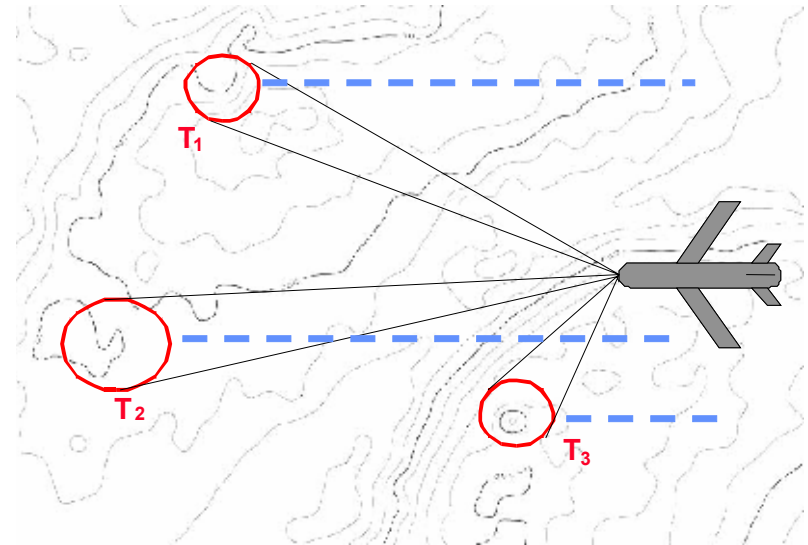
Database Integrity for Synthetic Vision Systems

Operational concept: compare sensed with stored data...

...when 'significant' differences occur, inform the pilot



Down-looking sensor to detect errors primarily in the vertical
[UdH, 5-01], [Gra, 6-99]



Fwd-looking sensor to detect errors both in the vertical & horizontal, and provide more “timely warnings...”

Fwd-looking lateral coverage should help detect errors while turning in flight

Fwd-looking sensor may reduce minimum detectable errors



Real-time monitoring (2/2)

Database Integrity for Synthetic Vision Systems

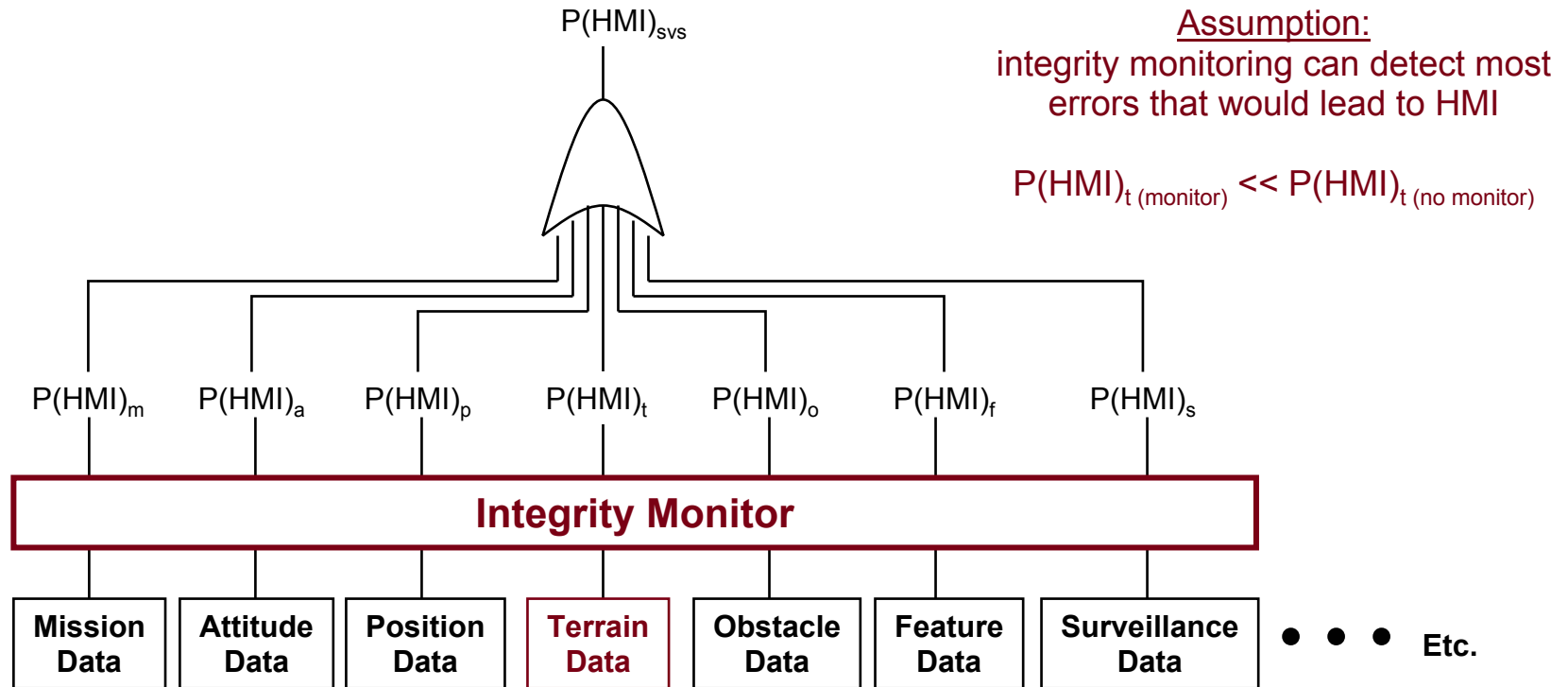
- **Conceptually similar to RAIM* [GPS, 96]**
 - Self-consistency check among available measurements
 - Assumes redundancy of information
 - Based on statistical detection theory
 - Integrity specification based on operational use
 - Uses past and present information
- **Different from RAIM**
 - Autonomous has different connotation
 - Time-to-alarm based on collision risk
 - Potential source of positioning integrity
- **Previous work suggests feasibility**
 - Integrity monitoring using radar altimeter [Gra, 6-99]
 - Precision approach using weather radar (APALS) [Die, 4-95]
 - Terrain-matching navigation (TERPROM, TERCOM) [Kay, 97]
- **Alternate Solution Paths**
 - Fault-avoidance (proof-of-correctness); not addressed here
 - Fault-tolerance (redundancy); not addressed here

*RAIM – Receiver Autonomous Integrity Monitor



Increasing Integrity*

Database Integrity for Synthetic Vision Systems



Critical factors: 'independence' and 'simplicity'



Candidate Sensors

Database Integrity for Synthetic Vision Systems

- Only two are commonly used on civil aircraft**
 - Radar altimeter (rigid mount)
 - Weather radar (scanning)
- Some do not provide range measurements**
 - MMW, FLIR
- High resolution sensors must consider weather effects**
 - Laser/LiDAR, MMW, FLIR
- GPS specular reflections may be a low-cost option**
- Cost uncertainties with sensors that are not certified**

Research to date has focused on:

- Radar altimeter
- Weather radar
- GPS based bi-static radar



Monitoring Approach – Radar Altimeter*

Database Integrity for Synthetic Vision Systems

Test Platforms



KA C90



B-757



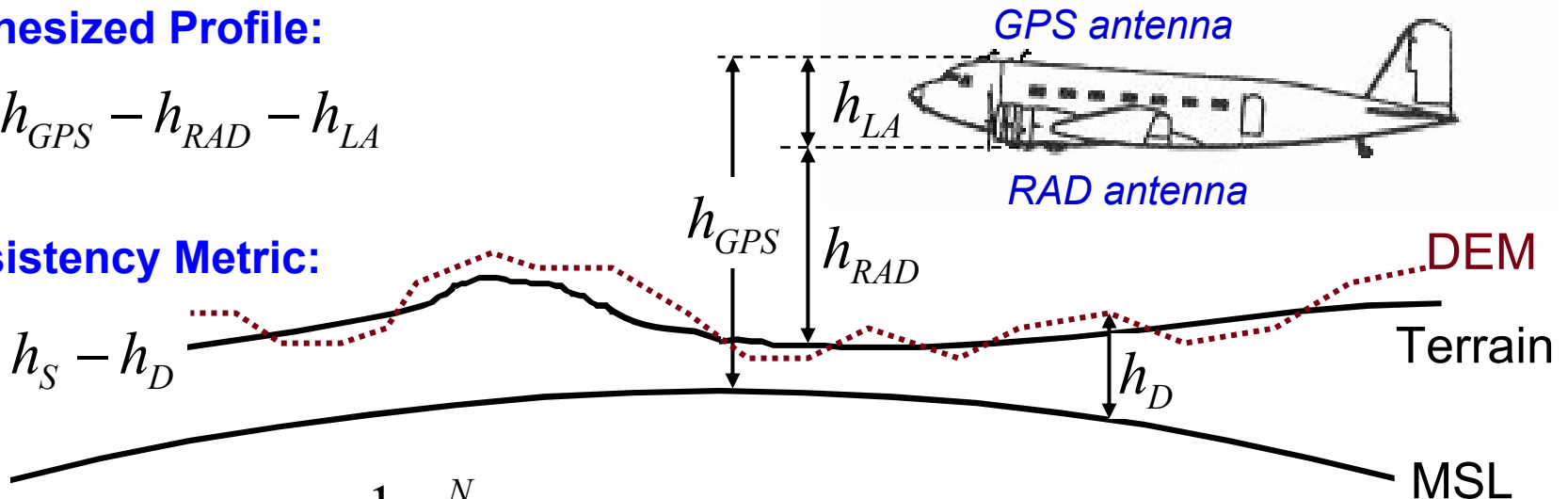
DC-3

Synthesized Profile:

$$h_S = h_{GPS} - h_{RAD} - h_{LA}$$

Consistency Metric:

$$p = h_S - h_D$$



Test Statistic:

$$T = \frac{1}{\sigma_p^2} \sum_{i=1}^N p^2(t_i)$$

← Thresholds established based on desired integrity

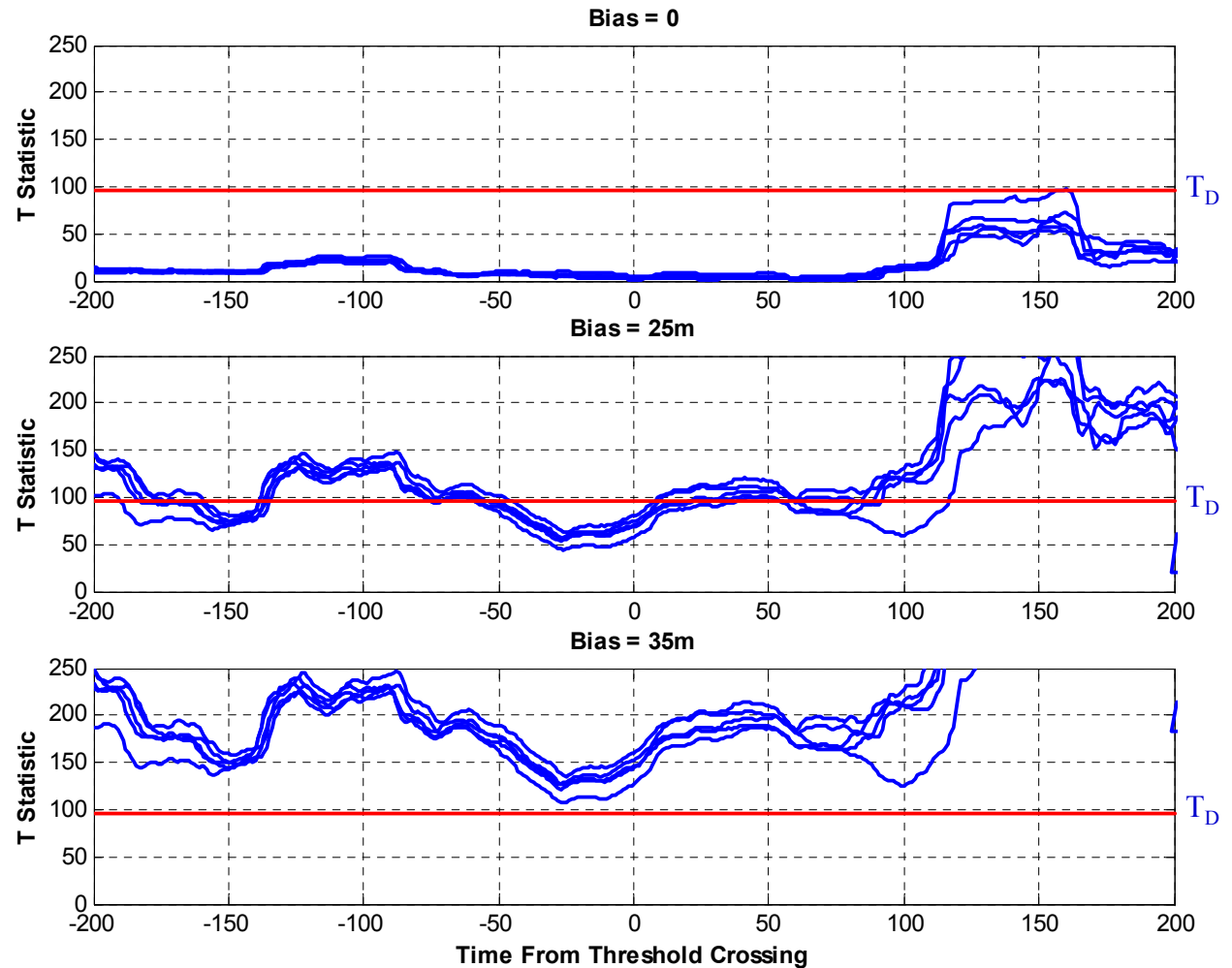


Selected Results – Radar Altimeter

Database Integrity for Synthetic Vision Systems

Configuration

P_{MD}	10^{-7}
P_{FA}	10^{-4}
N	50
T_D	96
MDB	34 m
DEM	3"

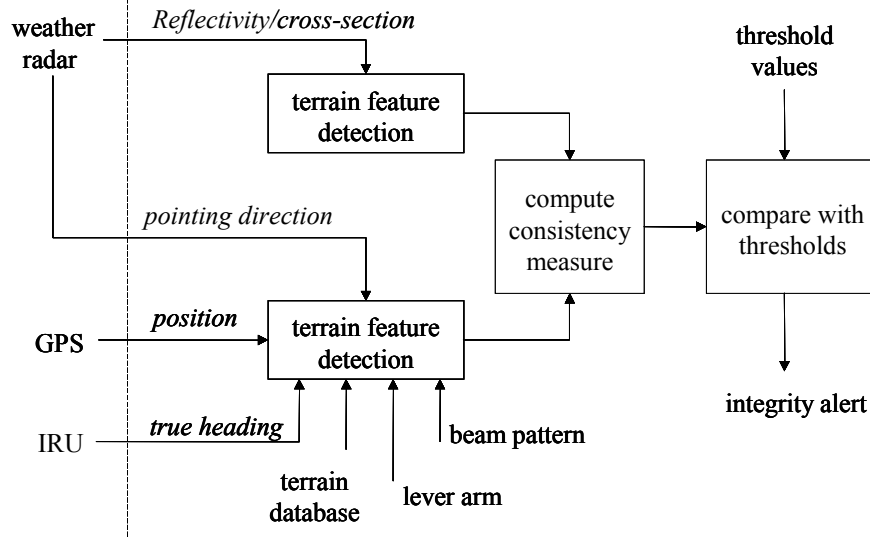
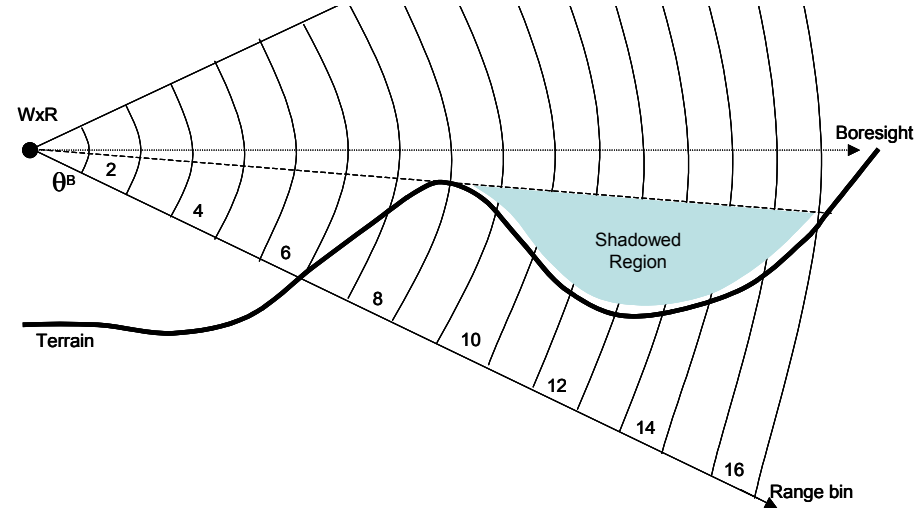


*Data acquired onboard B-757 test aircraft (Sep 2001)



Monitoring Approach – WxR

Database Integrity for Synthetic Vision Systems





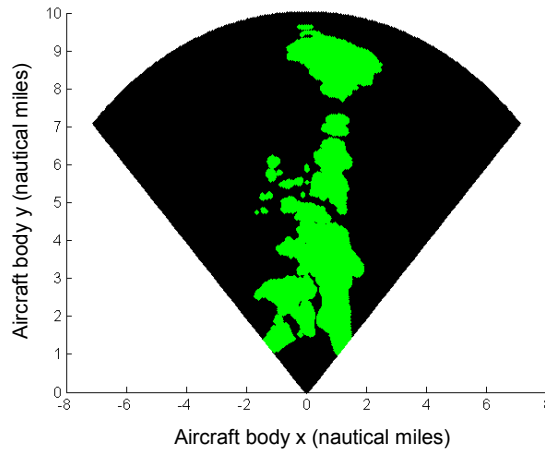
Selected Results – WxR

Database Integrity for Synthetic Vision Systems

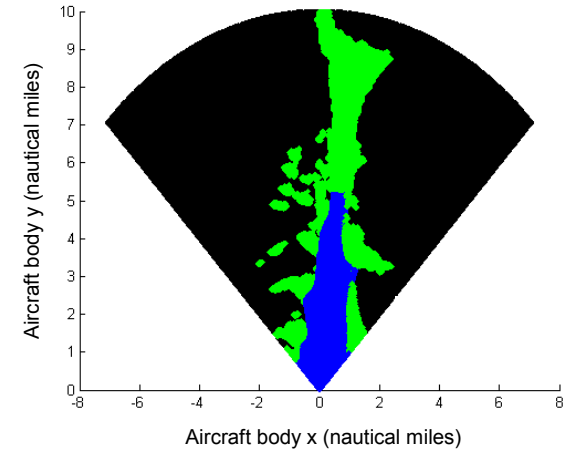
Sample Data (JNU) Bendix WxR King Air C90



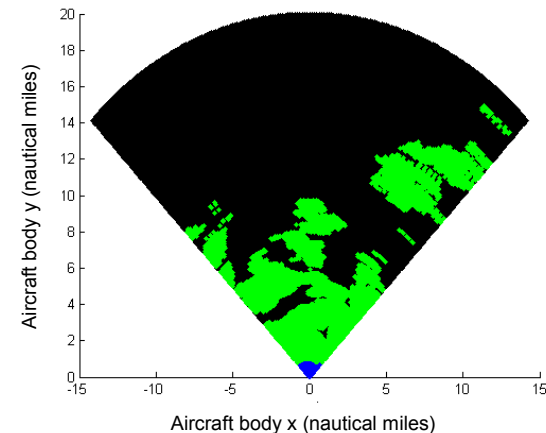
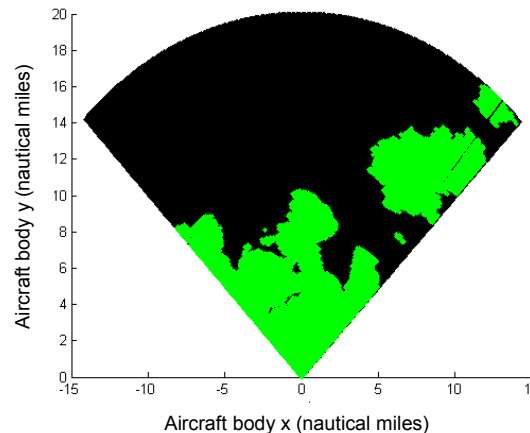
Radar-derived 'Measurements'



DEM-derived 'Measurements'



Sample Data (MOD) Rockwell-Collins WxR DC-8

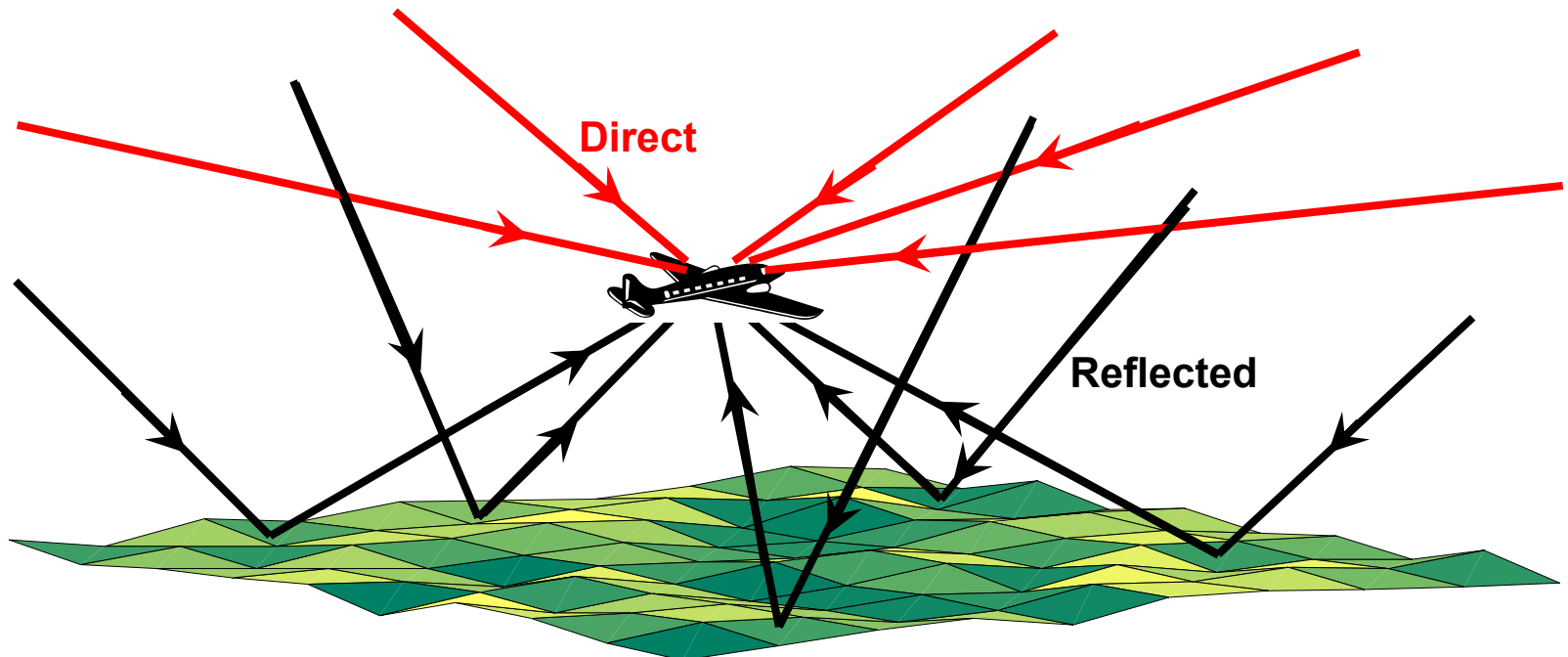




GPS-based Bi-static Radar*

Database Integrity for Synthetic Vision Systems

- Zenith antenna receives direct GPS signals
- Nadir antenna receives same GPS signals after reflection from surface below
- Derive path delay measurements (Direct – Reflected)
- Compute expected path delays using GPS position solution and a DEM
- Compare measured and computed results

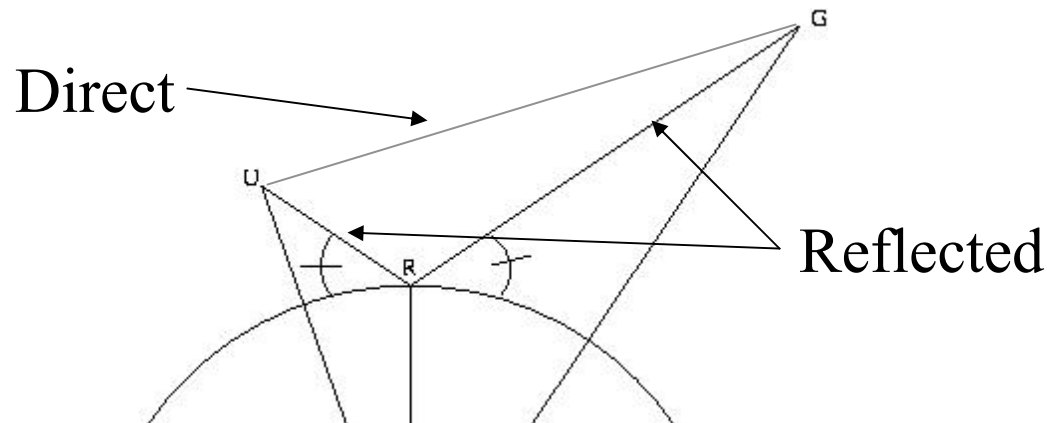




Expected Path Delay Construction

Database Integrity for Synthetic Vision Systems

- Use standard receiver (U) and satellite (G) position solutions
- Compute theoretical reflection point (R)
- Direct Path = $\|U-G\|$
- Reflected Path = $\|U-R\| + \|R-G\|$
- Path Delay = Reflected Path - Direct Path



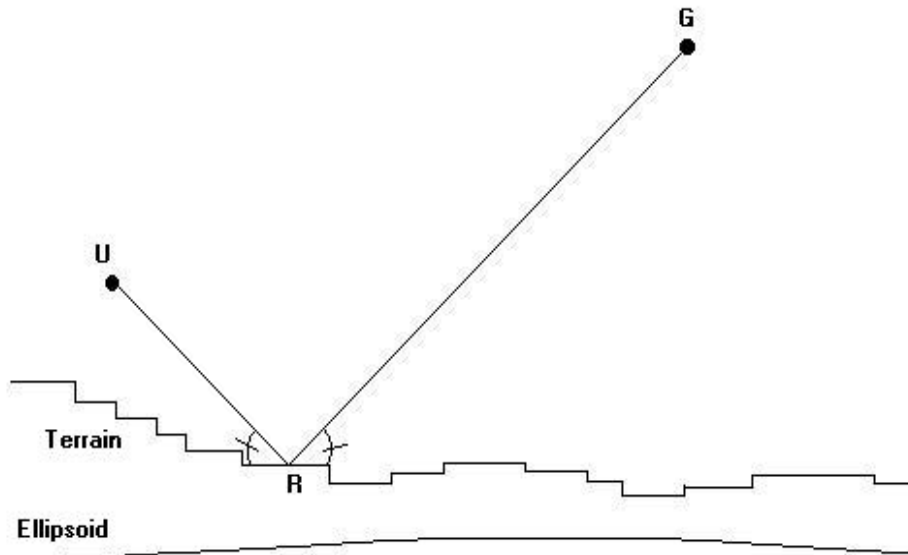


Computed Reflection Point

Database Integrity for Synthetic Vision Systems

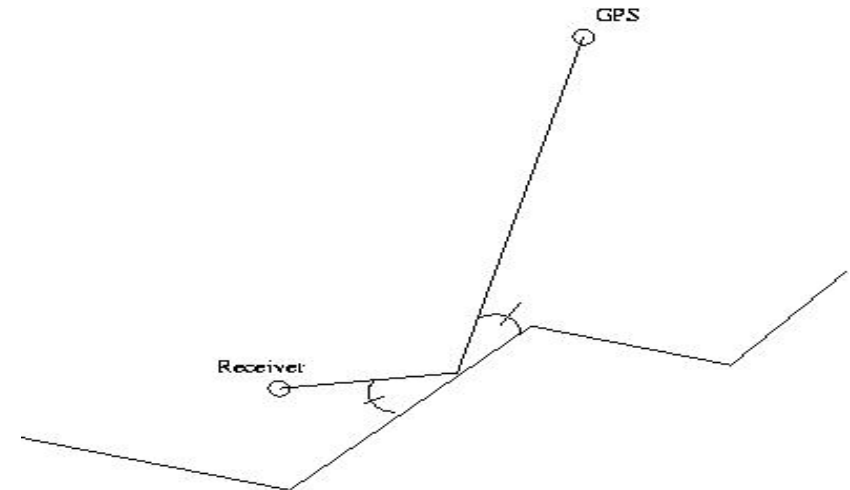
Terrain Iteration Method

Iterated on flat terrain until incident and reflection angles agree



Surface Tilts Method

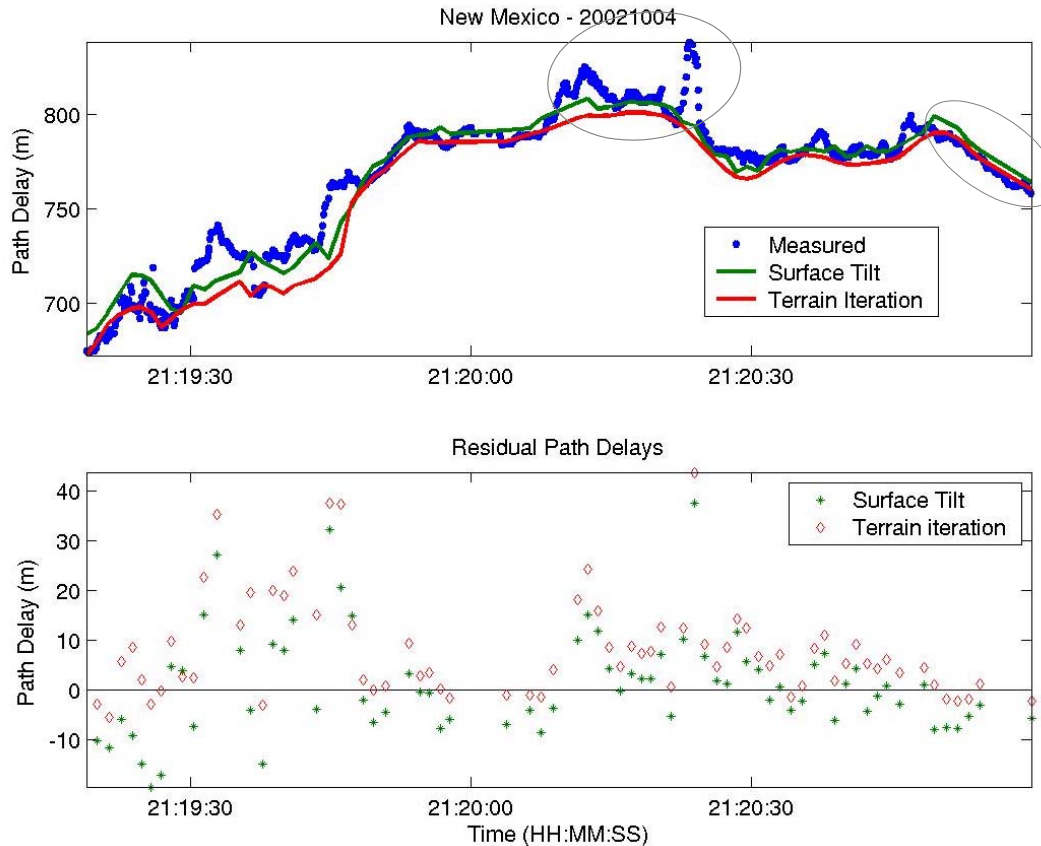
Evaluates all surface points around receiver for best geometry





Selected Results

Database Integrity for Synthetic Vision Systems



Overall:

RMS ~ 11.5m , STD ~ 10.3m

Noisy Region:

RMS ~ 11m, STD ~ 10m

Smooth Region:

RMS ~ 4m, STD ~ 1.5m

Performance affected by:

surface roughness
incidence angle
receiver height
dielectric constant
DEM quality



Summary of Monitor Research

Database Integrity for Synthetic Vision Systems

- Radar altimeter
 - ‘only software’, standard interface (A-429)
 - Validated on multiple platforms
 - No IRU required
 - Challenges: altitude and attitude dependencies
- Weather radar
 - ‘only software’, standard interface (A-708A)
 - Real-time validation upcoming
 - IRU required (A-429)
 - Challenges: real-time, agreement statistics, range resolution
- GPS Bi-static radar
 - ‘custom’ receiver, bottom-mount antenna, no IRU required
 - Can provide height above ground
 - Real-time validation upcoming
 - Challenges: real-time, multi-satellite, agreement statistics, availability



A few open issues...

Database Integrity for Synthetic Vision Systems

Operational requirements for integrity

- threat models specific to operational context

Further characterization of sensor and DEM errors

Identify technology limitations and mitigation designs

- WxR range resolution
- Real-time, multi-satellite tracking for bi-static radar

Operational proof-of-concept for WxR and GPS-based monitors

More attention to integrity of other data classes

- Obstacles
- Features
- ADS-B traffic
- CPDLC
- Nav data
- ...



Publications

Database Integrity for Synthetic Vision Systems

- Young, S., Uijt de Haag, M., Campbell, J., "An X-band Radar Terrain Feature Detection Method for Low-Altitude SVS Operations and Calibration Using LiDAR," submitted to SPIE Defense and Security Symposium to be held in Orlando, Florida, April 12-16, 2004
- Young, S., and Uijt de Haag, M., "A Shadow Detection and Extraction Algorithm Using Digital Elevation Models and X-band Weather Radar Measurements," submitted to the International Journal of Remote Sensing, February, 2004
- Young, S., Uijt de Haag, M., and Sayre, J., "Using X-band Weather Radar Measurements to Monitor the Integrity of Digital Elevation Models for Synthetic Vision Systems," 17th Annual International Symposium on Aerospace/Defense Sensing, Simulation, and Controls - AeroSense, International Society for Optical Engineering (SPIE), Orlando, Florida, April 21-25, 2003
- Sturtevant, P., Masters, D., Axelrad, P., and Katzberg, S., "GPS Based Bistatic Radar for Terrain Awareness – Methods and Preliminary Results," Institute of Navigation GPS/GNSS Conference, Portland, Oregon, September, 2003
- Young, S., Harrah, S., and Uijt de Haag, M., "Real-time Integrity Monitoring of Stored Geo-spatial Data using Forward-looking Remote Sensing Technology", 21st Digital Avionics Systems Conference, Irvine, California, October 28-31, 2002
- Uijt de Haag, M., Young, S., Sayre, J., Campbell, J., and Vadlamani, A., "DEM Integrity Monitor Experiment (DIME) Flight Test Results", 16th Annual International Symposium on Aerospace/Defense Sensing, Simulation, and Controls - AeroSense, International Society for Optical Engineering (SPIE), Orlando, Florida, April 1-5, 2002
- Uijt de Haag, M., Sayre, J., Campbell, J., Young, S., and Gray, R., "Terrain Database Integrity Monitoring for Synthetic Vision Systems", Transactions on Aerospace and Electronic Systems, Institute for Electronics and Electrical Engineers (IEEE), submitted December 21, 2001
- Uijt de Haag, M., Young, S., And Gray, R., "A Performance Evaluation of Elevation Database Integrity Monitors for Synthetic Vision Systems", 8th International Conference on Integrated Navigation Systems, Saint Petersburg, Russia, May 28-30, 2001
- Uijt de Haag, M., Sayre, J., Campbell, J., Young, S., And Gray, R., "Flight Test Results of a Synthetic Vision Elevation Database Integrity Monitor", 15th Annual International Symposium on Aerospace/Defense Sensing, Simulation, and Controls – AeroSense, International Society for Optical Engineering (SPIE), Orlando, Florida, April 16-20, 2001
- Uijt de Haag, M., Young, S., And Gray, R., "DTED Integrity Monitoring Using Differential GPS and Radar Altimeter", International Association of Institutes of Navigation (IAIN) World Congress in association with the U. S. Institute of Navigation (ION) Annual Meeting, San Diego, California, June 26-28, 2000